APPENDIX

Section 97.15(e) is amended to read as follows:

> (e) Except as otherwise provided in this section, a station antenna structure may be erected at heights and dimensions sufficient to accommodate amateur service communications.
>
> > (1) State and local regulation of a station antenna structure must not preclude amateur service communications. Rather, it must reasonably accommodate such communications; it must constitute the minimum practicable regulation to accomplish the state or local authority's legitimate purpose; and it must not impose substantial costs on amateur service licensees.
> >
> > (2) Any state or local antenna restriction or regulation which, on its face or as applied, would limit amateur station antennas to heights below 70 feet is presumed unreasonable unless the promulgating authority can demonstrate that such regulation is necessary to accomplish a clearly defined, and expressly stated health, safety or aesthetic objective; that there is no less burdensome alternative to the regulation; and that the Federal interest in efficient amateur radio communications from the amateur station at issue is otherwise reasonably accommodated.
> >
> > (3) Any state or local authority, or other entity that wishes to maintain and enforce zoning, land use or other regulations or restrictions inconsistent with this section may apply to the Commission for a full or partial waiver of this section. Such waivers may be granted by the Commission in its sole discretion, upon a showing by the applicant that local concerns of a highly specialized or unusual nature create an overwhelming necessity for regulation inconsistent with this section. No application for waiver shall be considered unless it includes the particular regulation for which waiver is sought. Waivers granted according to this

rule shall not apply to later-enacted or amended regulations by the local authority unless the Commission expressly orders otherwise.

Antenna Height and Communications Effectiveness

By Gerald L. Hall, K1TD
Associate Technical Editor

Copyright © 1987
The American Radio Relay League, Inc.
225 Main Street
Newington, CT 06111

EXECUTIVE SUMMARY

Amateur Radio communications between two distant points on the earth rely on signals propagating through the ionosphere. Acting as somewhat of a mirror at heights in the order of 150 miles, the ionosphere returns signals to the earth a thousand or more miles away.

The vertical angle of radiation is the key factor in determining effective communications distances beyond line of sight. For the greatest possible communications distance, the energy from the transmitter must be radiated at angles close to the horizon. For this to take place, a horizontal antenna must be placed high above the ground in terms of wavelengths. The length of a radio wave is inversely related to its frequency.

A beam type of antenna at a height of 70 feet or more will provide greatly superior performance over the same antenna at 35 feet, all other factors being equal. To a distant receiving station, a transmitting antenna at 70 feet will provide the effect of approximately 3 to 4 times more transmitter power than the same antenna at 35 feet. Depending on the level of noise and interference, this performance disparity is often enough to mean the difference between making distant radio contact with fairly reliable signals, and being unable to make distant contact at all. Thus, the antenna at 35 feet is unsatisfactory, while the same antenna at 70 feet is quite satisfactory. The 70-foot height is used only for the purpose of illustration, however, and should not be construed as the optimum height for antennas. Heights above 100 feet will give significantly better performance than at 70 feet.

If an amateur operator is restricted to the use of low antennas, it is reasonable to assume he will obtain more powerful transmitting equipment to compensate for the loss of antenna effectiveness. For example, he might increase his transmitter power from 500 watts to 1.5 kilowatts, to compensate for a three-fold loss in antenna effectiveness because of height limitations. This increase in power, in turn, increases the possibilities for his signal to overload nearby television and radio receivers, creating interference for viewers and listeners.

A high amateur antenna provides a greater degree of immunity from television interference than does a low antenna. The sole source of radiated RF energy from the Amateur Radio station is its antenna. Raising that antenna to an increased height, well above the level of existing antennas for television reception, will reduce the possibility of interference to television reception from fundamental overload.

Antenna Height and Communications Effectiveness

By Gerald L. Hall, K1TD
Associate Technical Editor

The purpose of this paper is to provide general information about communications effectiveness as related to the physical height of antennas. The performance of horizontal antennas at heights of 35 and 70 feet is examined in detail. Vertical arrays are not considered here because at short-wave frequencies, over average terrain and at low radiation angles, they are less effective than are horizontal antennas.

Ionospheric Propagation

Frequencies between 3 and 30 megahertz (abbreviated MHz) are often called the "short-wave" bands. In engineering terms this range of frequencies is defined as the high-frequency or HF portion of the radio spectrum. HF radio communications between two points that are separated by distances of more than about 15 to 25 miles depend almost solely upon propagation of radio signals through the ionosphere. The ionosphere is a region of the earth's upper atmosphere which is ionized by ultraviolet rays received from the sun.

The ionosphere has the property that it will refract or bend radio waves which pass through it. However, the ionosphere is not one single "blanket" of ionization. Instead, for reasons not fully understood, a few discrete layers are formed at different heights above the earth. From the standpoint of radio propagation, each ionized layer has distinctive characteristics, related primarily to different amounts of ionization in the various layers. The ionized layer which is most useful for HF radio communications is called the F layer.

The F layer exists at heights varying from approximately 130 to 260 miles above the earth's surface. Both the layer height and the amount of ionization depend upon the latitude from the equator, the time of day, the season of the year, and upon the level of sunspot activity. Sunspot activity varies generally in cycles that are approximately 11 years in duration, although short-term bursts of activity may create changes in propagation conditions that last for less than an hour. The ionosphere is not homogeneous, and is undergoing continual change. The F layer disappears at night in periods of low and medium solar activity, as the ultraviolet energy required to sustain ionization is no longer received from the sun. The amount of bending that will be imparted to a passing radio wave is related directly to the intensity of ionization in this layer, and to the frequency of the radio wave.

A triangle may thus be used to portray the cross-sectional path of ionospheric radio-wave travel, as shown in Fig 1. The base of the triangle is the surface of the earth between two distant points, and the apex of the triangle is the point which represents refraction in the ionosphere. If all the necessary conditions are met, the radio wave will travel from the first point on the earth's surface to the ionosphere, where it will be bent sufficiently to travel to the second point on the earth, many hundreds of miles away.

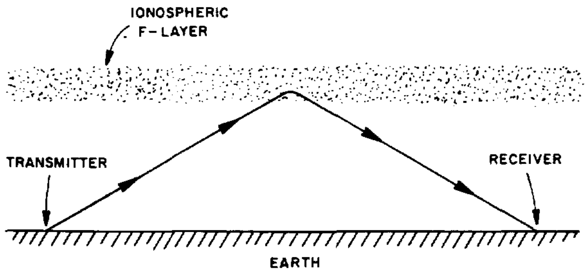

Fig 1—A simplified cross-sectional representation of ionospheric propagation. Typically the F layer exists at a height of 150 miles above the earth at mid-latitudes. The distance between the transmitter and the receiver may range from a few miles to 2500 miles under normal conditions.

Of course the earth's surface is not a flat plane, but instead is curved. High-frequency radio waves behave in essentially the same manner as light waves—they tend to travel in straight lines, but with a slight amount of downward bending caused by refraction in the air. For this reason it is not possible to communicate by a direct path over distances greater than about 15 to 25 miles in this frequency range. The curvature of the earth causes the surface to "fall away" from the path of the radio wave with greater distances. Therefore, it is the ionosphere that permits HF radio communication to be made between points separated by thousands of miles. The range of frequencies from 3 to 30 MHz is unique in this respect, as ionospheric propagation is not consistently supported for any frequencies outside this range.

One of the necessary conditions for ionospheric communications is that the radio wave must encounter the ionosphere at the correct angle. This is illustrated in Fig 2. Radio waves which leave the earth at high angles above the horizon may receive only very slight bending, and are then lost to outer space. For the same fixed frequency of operation, as the radiation angle is lowered toward the horizon, a point is reached where the bending of the wave is sufficient to return the wave

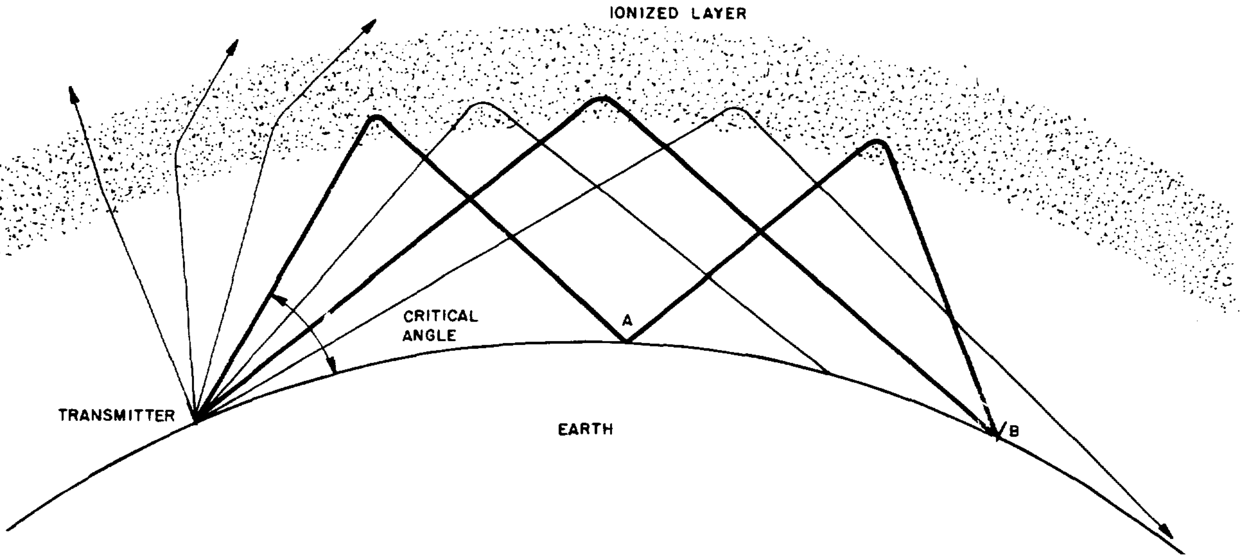

Fig 2—Behavior of radio waves encountering the ionosphere. Rays entering the ionized region at angles above the critical angle are not bent enough to be returned to earth, and are lost to space. Waves entering at angles below the critical angle reach the earth at increasingly greater distances as the angle approaches the horizontal. The maximum distance that may normally be covered in a single hop is 2500 miles. Greater distances may be covered with multiple hops.

to the earth. At successively lower angles, the wave returns to the earth at increasing distances.

If the radio wave leaves the earth at a radiation angle of zero degrees, just toward the horizon (or just tangent to the earth's surface), the maximum distance that may be reached under usual ionospheric conditions is approximately 2500 miles (4000 kilometers). However, the earth itself acts as a reflector of radio waves. Quite often a radio signal will be reflected from the reception point on the earth into the ionosphere again, reaching the earth a second time at a still more distant point.

As in the case of light waves, the angle of reflection is the same as the angle of incidence, so a wave striking the surface of the earth at an angle of, say, 15° is reflected upward from the surface at the same angle. Thus, the distance to the second point of reception will be approximately twice the distance of the first. This effect is also illustrated in Fig 2, where the signal travels from the transmitter at the left of the drawing via the ionosphere to Point A, in the center of the drawing. From Point A the signal travels via the ionosphere again to Point B, at the right. Signal travel from the earth through the ionosphere and back to the earth is called a hop. Under some conditions it is possible for as many as four or five signal hops to occur over a radio path, but no more than two or three hops is the norm. In this way, HF communications can be conducted over thousands of miles.

With regard to signal hopping, two important points should be recognized. First, a significant loss of signal occurs with each hop. Lower layers of the ionosphere absorb energy from the signals as they pass through, and the ionosphere tends to scatter the radio energy in various directions, rather than confining it in a tight bundle. The earth also scatters the energy at a reflection point. Thus, only a small fraction of the transmitted energy reaches a distant receiving point.

Again refer to Fig 2. Two radio paths (heavy lines) are shown from the transmitter to Point B, a 1-hop path and a 2-hop path. Measurements indicate that although there can be great variation in the ratio of the two signal strengths in a situation such as this, the signal power received at Point B will generally be from five to ten times greater for the 1-hop wave than for the 2-hop wave. (The terrain at the mid-path reflection point for the 2-hop wave, the angle at which the wave is reflected from the earth, and the condition of the ionosphere in the vicinity of all the refraction points are the primary factors in determining the signal-strength ratio.) Signal levels are generally compared in decibels, abbreviated dB. The decibel is a logarithmic unit. Three decibels difference in signal strengths is equivalent to a power ratio of 2:1; a difference of 10 dB equates to a power ratio of 10:1. Thus, the signal loss for an additional hop is about 7 to 10 dB.

The additional loss per hop becomes significant at greater distances. For a simplified example, a distance of 4000 miles can be covered in 2 hops of 2000 miles each or in four hops of 1000 miles each. For illustration, assume the loss for additional hops is 10 dB, or a 1/10 power ratio. Under such conditions, the 4-hop signal will be received with only 1/100 the power or 20 dB below that received in two hops. The reason for this is that only 1/10 of the 2-hop signal is received for the first additional (3rd) hop, and only 1/10 of that 1/10 for the second additional (4th) hop. It is for this reason that no more than four or five propagation hops are useful; the received signal becomes too weak to be heard.

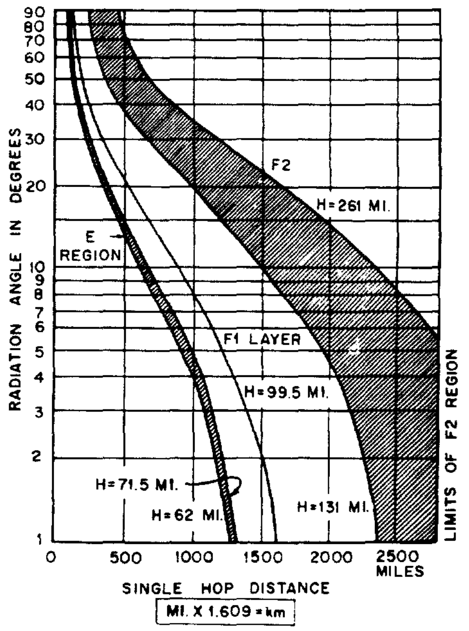

Fig 3—Distance plotted against wave angle (one-hop transmission) for the nominal range of virtual heights for the E and F2 layers, and for the F1 layer.

The second important point to be recognized in multihop propagation is that the trigonometry of the first hop generally establishes the trigonometry for all succeeding hops. And it is the radiation angle at the transmitter which sets up the trigonometry for the first hop. Solving a propagation triangle is simplified with the aid of the graph in Fig 3.[1] In this graph the radiation angle in degrees is given on the left, and the single-hop distance for the effective layer height along the bottom. Table 1 shows the optimum propagation distance for various radiation angles. The data for this table was read from the graph of Fig 3, based on an assumed F-layer height of 131 miles.

From Table 1, if the radiation angle from a given transmitting antenna is concentrated at 30°, the first and succeeding hops in radio propagation will span about 650 miles each. With a usable maximum limit of five hops under the best of conditions, one can project that the greatest distance for optimum communications for a 30° wave angle is five times 650 miles, or 3250 miles. For effective communications over greater distances, it would be necessary to lower the radiation angle at the transmitter antenna site. As will be discussed shortly, this can be done only by increasing the height of the horizontal transmitting antenna.

Although the discussion in the preceding paragraphs has been in terms of a transmitting antenna, the same principles apply when the antenna is used for reception. A high antenna will receive low-angle signals more effectively than will a low antenna. The point of these several paragraphs may be summarized briefly: **The vertical angle of radiation is the key factor in determining effective communications distances beyond line of sight.**

Table 1—Propagation Distance versus Radiation Angle
(Data extracted from Fig 3)

Radiation Angle, Degrees	*Optimum Propagation Distance, Miles*
2	2250
4	2100
8	1650
10	1500
15	1200
20	1000
30	650
40	450

Scientists and engineers recognize that modes other than signal hopping account for the propagation of radio waves over thousands of miles. However, studies of actual radio propagation in which the writer has participated have displayed signals with as many as 5 hops, so the hopping mode is one distinct possibility.[2] Whatever the propagation mode, there is unanimous agreement that the most effective communications at HF most often accompany the lowest radiation angle.

Horizontal Antennas

A simple antenna that is commonly used for HF communications is the horizontal half-wave dipole. The dipole is a straight length of wire (or tubing) into which radio-frequency energy is fed at the center. Because of its simplicity, the dipole may be easily subjected to theoretical performance analyses. Further, the results of proper analyses are borne out in practice. For these reasons, the half-wave dipole becomes a convenient performance standard against which other antenna systems can be compared. The dipole antenna, when viewed from one end, radiates an equal amount of power in all directions.

Because the earth acts as a reflector for HF radio waves, the directive properties of any antenna are modified considerably by the earth underneath it. If a dipole antenna is placed horizontally above the earth, most of the energy radiated downward from the dipole is reflected upward. The reflected waves combine with the direct waves (those radiated at angles above the horizontal) in various ways, depending on the height of the antenna, the frequency, and the electrical characteristics of the ground under and around the antenna.

At some vertical angles above the horizon, the direct and reflected waves may be exactly in phase—that is, the maximum signal or field strengths of both waves are reached at the same instant at some distant point. In this

---

[1] From *The ARRL Antenna Book*, 14th edition, Chapter 1, Fig 12.

[2] HF backscatter studies by Raytheon Company under contract with Rome Air Development Center, Griffiss AFB, NY. A part of this study was done at Raytheon's South Dartmouth, Mass. field site, Jan-Jun, 1960.

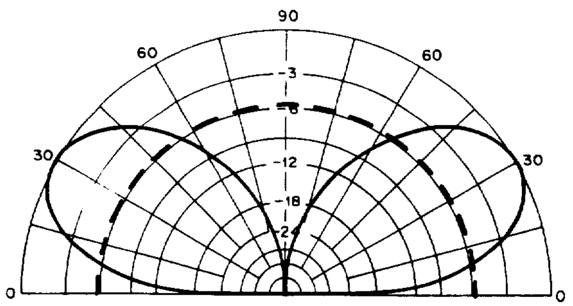

Fig 4—Elevation-plane pattern for a horizontal dipole at a height of ½ wavelength (solid line) and in free space (broken line).

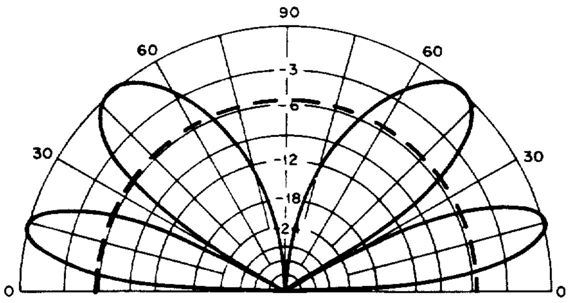

Fig 5—Elevation-plane pattern for a horizontal dipole at a height of 1 wavelength (solid line) and in free space (broken line).

case the resultant field strength is equal to the sum of the two components. At other vertical angles the two waves may be completely out of phase at some distant point—that is, the fields are maximum at the same instant but the phase directions are opposite. The resultant field strength in this case is the difference between the two. At still other angles the resultant field will have intermediate values. Thus, the effect of the ground is to increase the intensity of radiation at some vertical angles and to decrease it at others. The elevation angles at which the maxima and minima occur depend primarily on the antenna height above ground. (The electrical characteristics of the ground have some slight effect.)

If the earth is considered to be a perfect reflector, straightforward trigonometric calculations can be made to determine the relative amount of radiation intensity at any vertical angle for any dipole height. Graphs from such calculations may be plotted as circular or polar diagrams, called radiation patterns. Fig 4 shows the vertical radiation pattern for a dipole antenna positioned one-half wavelength above the ground, viewed from one end, and Fig 5 for a height of one wavelength. The radiation from the dipole if in free space is shown by the broken lines, and appear as semi-circles.

In the plots of Figs 4 and 5, the radiation angle above the horizon is represented in the same fashion that angles are measured on a protractor. The concentric circles are calibrated to represent ratios of field strengths, referenced to the strength represented by the outer circle. The circles are calibrated in decibels. Diminishing strengths are plotted toward the center.

Table 2—Electrical Heights For Amateur Bands below 30 MHz

Frequency	*35 feet physical height*	*70 feet physical height*
1.8 MHz	0.06 wavelength	0.13 wavelength
3.5	0.12	0.25
7.0	0.25	0.50
10.1	0.36	0.72
14.0	0.50	1.00
18.1	0.64	1.29
21.0	0.75	1.49
24.9	0.89	1.77
28.0	1.00	1.99

Antenna heights are usually discussed in terms of wavelengths. The reason for this is that the length of a radio wave is inversely proportional to its frequency. Therefore a fixed physical height will represent different electrical heights at different radio frequencies. For example, a height of 70 feet represents one wavelength at a frequency of 14 MHz. But the same 70-foot height represents only ½ wavelength for a frequency of 7 MHz. For physical antenna heights of 35 and 70 feet, Table 2 shows the electrical heights in wavelengths for all the amateur bands below 30 MHz.

The lobes and nulls of the pattern of Figs 4 and 5 illustrate what was described earlier, that the effect of the earth beneath the antenna is to increase the intensity of radiation at some vertical angles and to decrease it at others. At a height of ½ wavelength (Fig 4), the radiated energy is strongest at a radiation angle of 30°, an angle which was determined earlier to provide a maximum effective communications distance of about 3250 miles under the conditions assumed. The pattern of Fig 4 represents the radiation from a dipole for 14 MHz at a height of 35 feet.

As the horizontal antenna is raised to even greater heights, additional lobes are formed, and those that exist move closer to the horizon. But yet the maximum amplitude of the existing lobes is not diminished. As may be seen from Fig 5, for an antenna height of 1 wavelength, the energy in the lower lobes is strongest at 15°. And Table 1 indicates that the optimum propagation distance per hop for 15° is 1200 miles.

Under the very same conditions as before, 5-hop propagation, one may see that the greatest distance for optimum communication now is 5 × 1200 or 6000 miles. The pattern of Fig 5 represents a 14-MHz dipole at a height of 70 feet. Thus, for the conditions assumed, the optimum communications distance has been extended from 3250 miles to 6000 miles, merely by raising the antenna from 35 to 70 feet. Even greater heights would provide still greater communications distances under the same conditions.

The radiation angle of the lowest lobe for a horizontal antenna above the ground may be determined mathematically:

$$\theta = \sin^{-1}\left(\frac{0.25}{h}\right)$$

where

θ = the wave angle or radiation angle
h = the antenna height above ground in *wavelengths* (see Table 2)

In short, the higher the horizontal antenna, the lower is the lowest lobe of the pattern. Therefore, the higher an HF antenna can be placed, the farther it will provide effective communications because of the resulting lower radiation angle. This is true for any horizontal antenna.

Electrical Characteristics of HF Antennas

As mentioned previously, a dipole antenna, when viewed from one end of the conductor, radiates an equal amount of power in all directions. The plotted radiation pattern is a perfect circle. If the dipole is vertical, this circle represents the azimuth coverage, with an equal amount of power radiated in every compass direction. For point-to-point communications, however, it is beneficial to concentrate the radiated energy into a beam which is aimed toward a single distant point. An analogy can be made by comparing the light emanating from a bare electric lamp to that from an automobile headlight. For illuminating a distant point, the headlight is far more effective.

Antennas designed to concentrate the radiated energy into a beam are called beam antennas. For a fixed amount of transmitter power fed to the transmitting antenna, beam antennas provide increased signal strength at a distant receiver. In radio communications, the use of a beam antenna is also beneficial during reception, because the antenna pattern for transmission is the same as for reception. A beam antenna helps to reject signals from unwanted directions, and in effect boosts the strength of signals received from the desired direction.

The increase in signal or field strength which a beam antenna offers is frequently referenced to a dipole antenna by a term called gain. Gain is commonly expressed in decibels. One type of beam antenna is a Yagi, named after one of its Japanese inventors. Different varieties of Yagi antennas exist, each having somewhat different characteristics. Many antennas erected for television reception are a form of multi-element Yagi beam.

Subsequent discussions in this paper refer to a 3-element Yagi array, one having a driven element, a parasitic director and a parasitic reflector. The parasitic elements are not fed any power directly; instead they are excited through mutual coupling to the driven element, and in turn also radiate power. Each parasitic element is spaced 0.2 wavelength from the driven element, and the theoretical gain of this array, determined through computer analysis, is 7.2 dB over a dipole. This means that for the same transmitter power, the effective radiated power of the Yagi in its favored direction is 5.2 times that of the dipole in the same direction. The theoretical front-to-back ratio of the Yagi antenna is 12 dB, meaning the power radiated in its forward direction is 15.7 times that radiated in the opposite direction. Values for a practical antenna of this type are quite close to theoretical.

Computer-calculated radiation patterns for the horizontal Yagi array are presented in Figs 6 and 7. Fig 6 shows the azimuth plane, the response in various

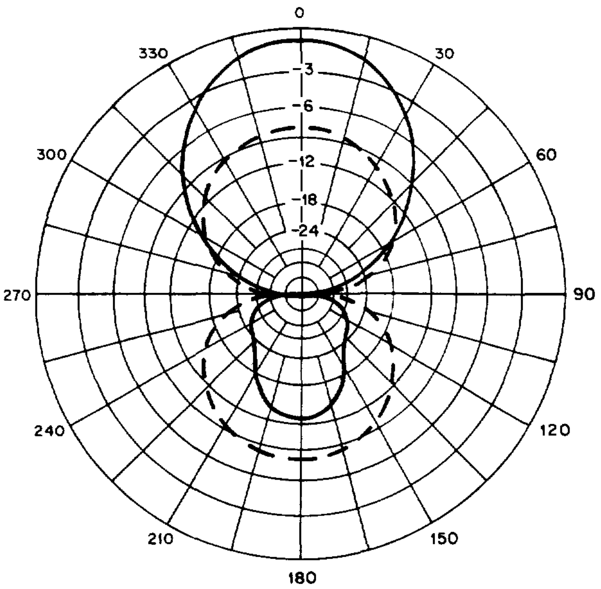

Fig 6—Computer-calculated azimuth-plane radiation pattern for a horizontal 3-element Yagi array (solid line), and for a comparison dipole (broken line).

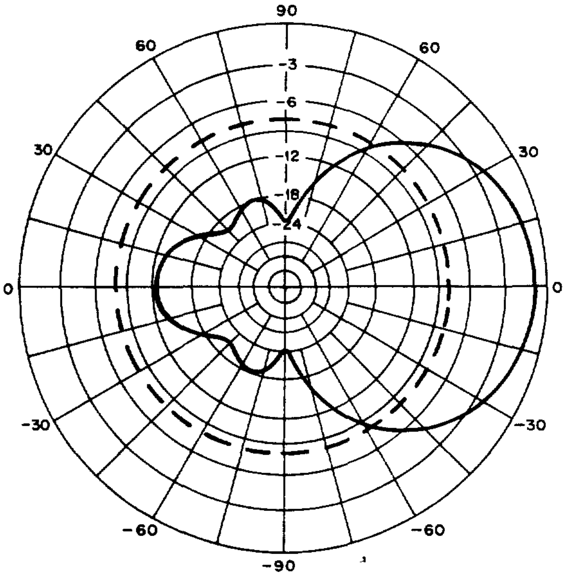

Fig 7—Computer-calculated elevation-plane or vertical-profile pattern of a horizontal Yagi array, solid line, and for a comparison dipole, broken line. These patterns are those seen from the ends of the elements with the antennas in free space.

compass directions, as a solid line. The broken line in Fig 6 shows the pattern of a half-wavelength dipole, for comparison. Fig 7 shows the elevation plane or vertical-profile pattern. This pattern is that seen from the ends of the elements, with the antenna in free space. The solid line again represents the Yagi, and the broken line the dipole, that "perfect circle" which was mentioned earlier. Performance of most other Yagi-type arrays with three or four elements will not be significantly different from the patterns shown here.

Another often-used type of beam antenna is the quad array. Typically, a quad is constructed with two or more wire elements in the form of a square or a diamond. The conducting wires are usually supported by X-shaped frames of wood or fiberglass material. For the same number of elements and spacing, the performance of a quad beam is generally similar to that of a Yagi beam.

The vertical patterns of Figs 4 and 5 were calculated by assuming the earth is a perfect reflector, an unrealistic situation. Actual earth does not reflect all of the radio-frequency energy striking it; some absorption takes place. Over real earth, therefore, the patterns will be slightly different, depending upon the electrical conductivity and dielectric constant of the soil, and upon the radio frequency. Computer programs are available to take these factors into account, and reliable calculations of patterns over real earth may be made. Yagi patterns over real earth are shown in Figs 8 through 14. These patterns were calculated with an Apple IIe personal computer.[3] "Average" soil conditions were used for these plots, that is, a conductivity of 5 millisiemens per meter and a dielectric constant of 15.[4] These patterns compare the performance of Yagi arrays at heights of 35 and 70 feet. In Figs 8 through 12, the broken line is the plot for a 35-foot height, and the solid line for 70 feet. For 24.9 and 28 MHz, Figs 13 and 14, it is helpful to present the 35- and 70-foot patterns in separate graphs, for clarity. Otherwise the multiple lobes become indistinguishable.

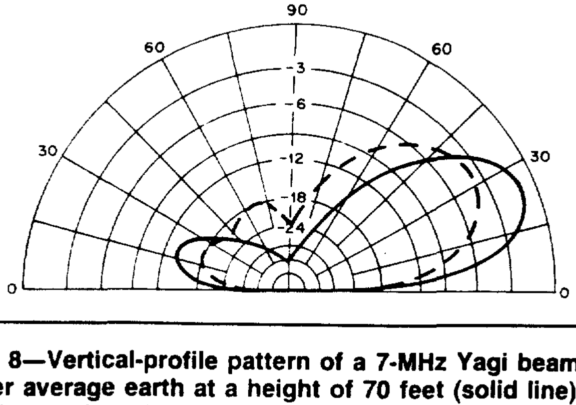

Fig 8—Vertical-profile pattern of a 7-MHz Yagi beam over average earth at a height of 70 feet (solid line) and at 35 feet (broken line).

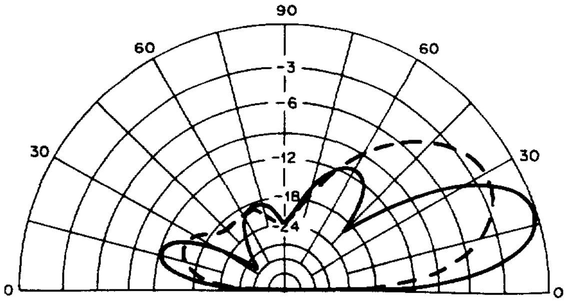

Fig 9—Vertical-profile pattern of a 10.1-MHz Yagi beam at 70 feet (solid line) and at 35 feet (broken line).

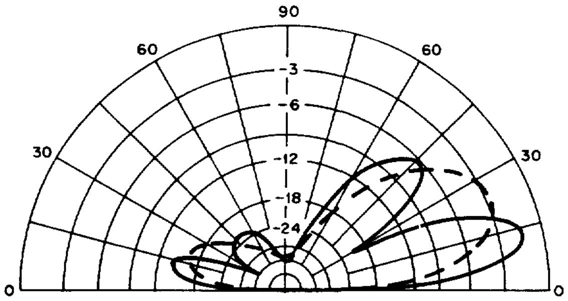

Fig 10—Vertical-profile pattern of a 14-MHz Yagi beam at 70 feet (solid line) and at 35 feet (broken line).

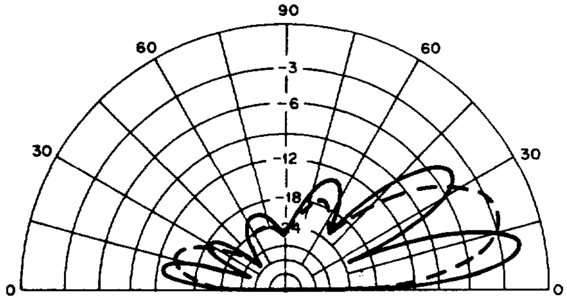

Fig 11—Vertical-profile pattern of an 18.1-MHz Yagi beam at 70 feet (solid line) and at 35 feet (broken line).

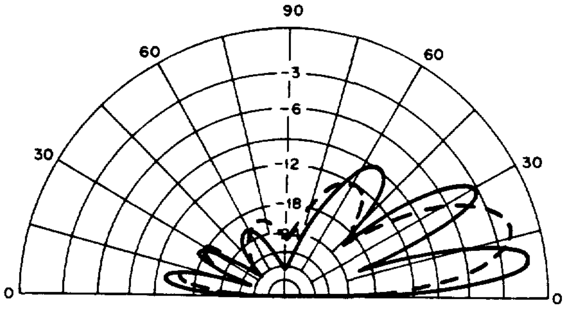

Fig 12—Vertical-profile pattern of a 21-MHz Yagi beam at 70 feet (solid line) and at 35 feet (broken line).

---

[3] A commercially available software program, ANNIE, was used to calculate all patterns presented in this paper.

[4] Such soil conditions may be considered typical for the central part of the United States, such as the Ohio and Mississippi river valleys.

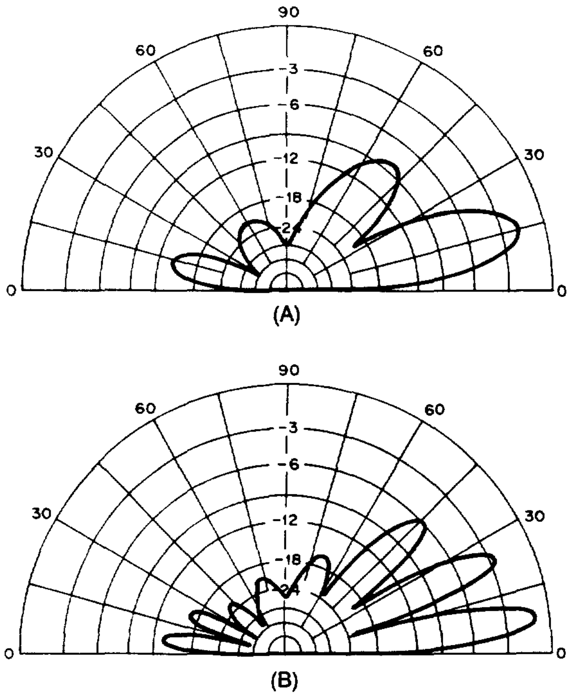

Fig 13—At A, vertical-profile pattern of a 24.9-MHz Yagi beam at 35 feet, and at B, 70 feet.

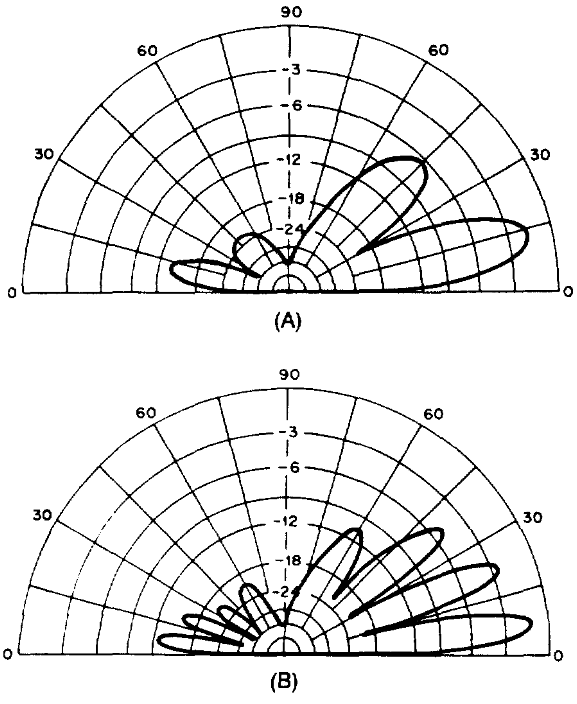

Fig 14—At A, vertical-profile pattern of a 28-MHz Yagi beam at 35 feet, and at B, 70 feet.

Table 3—Comparison of Yagi Beams at Heights of 35 and 70 Feet

Frequency	**(-At 35 Feet-)** *Elev. angle of max. radiation*	**(-At 70 Feet-)** *Elev. angle of max. radiation*	*Performance difference at 5°*
7.0	34 degrees	24 degrees	5.7 decibels
10.1	29	18	5.7
14.0	24	14	5.6
18.1	20	11	5.4
21.0	18	9	5.2
24.9	15	8	4.9
28.0	14	7	4.6

Fig 8 shows the vertical profile for 7-MHz Yagi beams. For a height of 35 feet, the energy is maximum at a vertical angle of 34° above the horizon. At a height of 70 feet, maximum radiation occurs at an angle of 24°. This is 10° lower than for the same antenna at 35 feet. In addition, in the 2- to 10-degree elevation range, those angles that are necessary for communicating over thousands of miles, the performance of the low Yagi beam is nominally 5.6 dB below that of the high Yagi. At a wave angle of 5.0°, the response of the Yagi at 70 feet is superior by 5.7 dB.

Similar data can be obtained from Figs 9 through 14 for the amateur frequencies from 10.1 through 28 MHz. The differences in performance for the amateur bands from 7 to 28 MHz are summarized in Table 3.

As Table 3 indicates, a Yagi antenna at 70 feet provides far greater radiation at low angles for all frequencies than the same antenna at 35 feet. This translates to greater communications effectiveness at long distances, and is especially true for the lower frequencies. At a 5° wave angle, the differences in field strengths range from 4.6 to 5.7 dB. This means that the power at a distant receiving antenna for most propagation conditions will be from 2.9 to 3.7 times stronger from a Yagi antenna at 70 feet, compared to the same Yagi at 35 feet. Heights greater than 70 feet will produce even higher power ratios.

In summary, a high Yagi antenna provides superior performance over a low Yagi, all other factors being equal. Depending on the level of noise and interference, the performance differences related to height are often enough to mean the difference between making distant radio contact with fairly reliable signals, and being unable to make contact at all.

Very High and Ultra High Frequencies

Commonly used amateur frequencies higher than those discussed earlier are the very high frequency portion of the spectrum, abbreviated VHF, and the ultra high frequencies, or UHF. The VHF range covers 30 to 300 MHz, and the UHF range from 300 to 3000 MHz.

In an earlier section it was mentioned that HF antennas must be large to be effective. To some degree, however, those considerations are not unique to that frequency range. They apply in general to VHF and UHF as well. A difference at VHF and UHF is that antennas may be physically small in order to realize optimum electrical lengths. However, a disadvantage of physically small antennas is that they present less surface area to passing radio waves, and are therefore less effective in picking up incoming signals. This effect is termed pickup efficiency. Pickup efficiency is reciprocative; it applies to transmitted signals as well as to received signals. To obtain higher pickup efficiency and therefore greater communications effectiveness, many antenna elements are required at VHF and UHF. The elements are usually installed on multiple booms. Single, vertical radiators, even at elevated heights, are ineffective for distances beyond a few miles at these frequency ranges. This is true because of low pickup efficiency and because of the omnidirectional characteristic of the radiator. Stacked vertical radiators are sometimes used to obtain gain with omnidirectional coverage.

Although ionospheric propagation does sometimes occur at the lower end of the VHF range, propagation at 100 MHz and above is almost always over a line-of-sight path. Under usual conditions, signals at these frequencies encounter very little refraction in air. Therefore it behooves a person using these frequencies to place his antenna as high as possible, so it can "see" farther. Certainly the antenna must be above surrounding objects, such as dense foliage and man-made structures. Such objects absorb radio-frequency energy in this portion of the spectrum, and therefore tend to block the signal from propagating. Objects such as hills, steel structures and many commercial or industrial buildings will block VHF signals to an even greater degree, creating "shadows" behind them.

At VHF and UHF, the lowest lobes for Yagi arrays at 35 and 70 feet are only a few degrees above the horizontal. However, for line-of-sight communications, the radiation angle should be zero, if possible, unless one wishes to communicate with airplanes or objects in outer space. Even more desirable are negative angles from high locations, so the antenna can "look down on" the terrain. At VHF and UHF the radiation angles for 35-foot heights are twice those occurring for the 70-foot heights. Therefore at VHF it is also beneficial to place the antenna as high as possible, and in the clear from surrounding objects.

Amateur Radio operators wishing to contact other amateurs at great distances use a time-worn but true expression, "For the best results, put your antenna as high as you possibly can." Many amateurs in various parts of the world put their big antennas atop 120-foot towers, and enjoy communications with amateurs in foreign countries when neighboring amateurs with much lower antennas cannot even hear the foreign signals.

Conclusion

The preceding information has dealt with antenna height and communications effectiveness. It has been shown that for all amateur frequencies, high horizontal antennas will outperform low antennas. Information has been developed to show a consistent power gain of the higher antennas over low ones, that is, at 70 feet and 35 feet. The 70-foot height was chosen only for the purpose of illustration, and is not intended to be construed as the optimum height for antennas. Heights above 100 feet will give significantly better performance than at 70 feet.

It is reasonable to assume that if an amateur operator is restricted to the use of low antennas, he will obtain transmitting equipment with a corresponding increase in power output to compensate for the loss of antenna effectiveness. For example, he might increase his transmitter power from 500 watts to 1.5 kilowatts to compensate for a three-fold loss in antenna effectiveness because of height limitations. It should be realized that this increase in power, in turn, increases the possibilities for his stronger signal to overload nearby television and radio receivers, creating interference for viewers and listeners.

There is one further consideration concerning amateur antenna height with regard to television and radio interference. In essence, the sole source of radiated RF energy from an Amateur Radio station is its antenna. Raising that antenna to an increased height, far above the level of existing antennas for television reception, will reduce the possibility of interference to television reception from fundamental overload.

APPENDIX B

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Modification and Clarification of Policies and	)	
Procedures Governing Siting and Maintenance	)	RM-8763
of Amateur Radio Antennas and Support	)	
Structures, and Amendment of Section 97.15	)	
of the Commission's Rules Governing the	)	
Amateur Radio Service.	)	

ORDER

Adopted: November 18, 1999 **Released: November 19, 1999**

By the Deputy Chief, Wireless Telecommunications Bureau:

I. Introduction and Executive Summary

1. In this *Order*, we address a Petition for Rule Making (Petition), filed on February 7, 1996, by The American Radio Relay League, Inc. (ARRL or Petitioner), asking that the Commission review and modify its policies and procedures pertaining to the Commission's limited preemption of state and local regulations affecting amateur radio facilities. The Petitioner also requests that the Commission amend Section 97.15 of the Commission's Rules to clarify the Commission's preemptive intent with respect to such state and local regulations.[1] We have carefully reviewed the requests, and the supporting arguments, and conclude that the modifications and clarifications suggested by Petitioner would not serve the public interest, convenience and necessity. Therefore, the Petition is denied.

II. Background

2. In 1984, ARRL petitioned the Commission for a declaratory ruling that would limit local regulatory control of amateur stations.[2] It was believed that local building codes and zoning regulations had limited the communications ability of licensees in the amateur service.[3] An outdoor antenna is a necessary component for most types of amateur service communications.[4] Municipalities and local land

---

[1] ARRL Petition for Rule Making, filed February 7, 1996, at i (RM-8763).

[2] ARRL Request for Issuance of a Declaratory Ruling, filed July 16, 1984.

[3] Petition at 3.

[4] *Id.*

use regulatory authorities regulated the heights, placement and dimensions of antennas.[5] In *PRB-1*, resolving the ARRL's declaratory ruling petition, the Commission noted that these regulations often result in conflict because the effectiveness of the communications that emanate from an amateur radio station is directly dependent upon the location and the height of the antenna.[6] Consequently in *PRB-1*, the Commission enunciated the Federal policy toward state and local regulatory restrictions on amateur station facilities.[7]

3. In the *MO&O*, the Commission declared a limited preemption of state and local regulations governing amateur station facilities, including antennas and support structures.[8] The Commission determined that there was a strong Federal interest in promoting amateur service communications, and that state and local regulations that preclude amateur service communications are in direct conflict with Federal objectives and must be preempted.[9] Furthermore, the Commission stated that a local ordinance or zoning regulation must make reasonable accommodation for amateur communications and must constitute the minimum practicable regulation to accomplish the local authority's legitimate purpose.[10] However, the Commission did not extend the limited preemption to covenants, conditions and restrictions (CC&Rs) in deeds and in condominium by-laws because they are contractual agreements between private parties.[11] Petitioner, *inter alia*, requests the extension of the limited preemption to such CC&Rs.[12]

4. Petitioner also requests other clarifications to *PRB-1*, as follows: (a) that local governments must make a reasonable accommodation for amateur radio antennas, rather than balancing their own local interests against the Federal interest in amateur radio; (b) that local governments could not specify a lower height maximum than sixty to seventy feet for an amateur radio antennna structure; (c) that overly burdensome conditions in land use authorizations or imposition of excessive costs is preempted; (d) that denial of a particular use permit or special exception does not relieve a local government from having to make a reasonable accommodation for amateur communications; (e) that conditional use permit procedures can be used to regulate amateur radio antennas, but only as an adjunct to a reasonable height restriction; and, (f) that land use restrictions pertaining to safety that limit the overall height of an amateur radio antenna structure, or restrict installation of an antenna altogether, are invalid unless there is no other alternative available that is less burdensome and still accomplishes the same purpose.[13] The Commission

---

[5] *Id.*

[6] Federal preemption of state and local regulations pertaining to amateur radio facilities, *Memorandum Opinion and Order*, *PRB-1*, 101 FCC 2d 952, 953 ¶ 3 (1985) (*MO&O* or *PRB-1*).

[7] *MO&O*.

[8] *Id.* at 960 ¶ 24.

[9] *Id.* at 959, 960 ¶ 24.

[10] *Id.* at 960 ¶ 25.

[11] *MO&O* at 954 ¶ 7 and 960 at ¶ 25 n.6.

[12] Petition at 22 and 23.

[13] *Id.* at i.

sought comment on the Petition on February 21, 1996.[14]

5. Since the adoption of the Commission's limited premption policy in *PRB-1*, Congress enacted Section 704 of the Telecommunications Act of 1996,[15] concerning the siting of personal wireless service facilities. We note that Section 704 of the Telecom Act encompasses commercial mobile radio services, unlicensed wireless services and common carrier wireless exchange access services.[16] Thus, Section 704 of the Telecom Act, which, among other things, bars state or local regulations that prohibit or have the effect of prohibiting the provision of personal wireless services, does not apply to stations or facilities in the amateur radio service.

III. Discussion

6. The Commission's policy with respect to restrictive covenants is clearly stated in the *MO&O* establishing a limited preemption of state and local regulations. In the *MO&O*, the Commission stated that *PRB-1* does not reach restrictive covenants in private contractual agreements.[17] The Petitioner argues that enforcement of a covenant by the court constitutes "state action", thus converting what otherwise would be a private matter into a matter of state regulation and, thus, subject to the Commission's limited preemption policy.[18] Notwithstanding the clear policy statement that was set forth in *PRB-1* excluding restrictive covenants in private contractual agreements as being outside the reach of our limited preemption,[19] we nevertheless strongly encourage associations of homeowners and private contracting parties to follow the principle of reasonable accommodation and to apply it to any and all instances of amateur service communications where they may be involved. Although we do not hesitate to offer such encouragement, we are not persuaded by the Petition or the comments in support thereof that specific rule provisions bringing the private restrictive covenants within the ambit of *PRB-1* are necessary or appropriate at this time. Having reached this conclusion, we need not resolve the issue of whether, or under what circumstances, judicial enforcement of private covenants would constitute "state action."

7. Petitioner further requests a clarification of *PRB-1* that local authorities must not engage in balancing their enactments against the interest that the Federal Government has in amateur radio, but rather must reasonably accommodate amateur communications.[20] We do not believe a clarification is necessary because the *PRB-1* decision precisely stated the principle of "reasonable accommodation". In *PRB-1*, the

---

[14] *Public Notice,* Petitions for Rulemaking Filed, Report No. 2122, Feb. 21, 1996. Eighteen comments were received. Two of the comments contained numerous signatures of amateur operators indicating that they supported the Petition.

[15] Telecommunications Act of 1996, Pub. L. No. 104-104, § 704; 110 Stat. 56 (1996) (Telecom Act) codified at 47 U.S.C. § 332.

[16] 47 U.S.C. § 332(c) (7)(C)(i).

[17] *MO&O* at 954 ¶ 7 and at 960, ¶ 25 n.6.

[18] Petition at 22 and 23.

[19] *MO&O* at 954 ¶ 7 and 960 at ¶ 25 n.6.

[20] Petition at 27.

Commission stated: "Nevertheless, local regulations which involve placement, screening, or height of antennas based on health, safety, or aesthetic considerations must be crafted to accommodate reasonably amateur communications, and to represent the minimum practicable regulation to accomplish the local authority's legitimate purpose."[21] Given this express Commission language, it is clear that a "balancing of interests" approach is not appropriate in this context.

8. Petitioner also requests establishment of sixty or seventy feet as the minimum height in a metropolitan area for an amateur antenna structure so that local authorities could not specify a lower height maximum for an amateur antenna.[22] Petitioner argues that such a minimum height would minimize interaction between amateur stations and home electronic equipment and provide reasonable antenna efficiency at different amateur frequencies, MF through UHF and beyond.[23] Petitioner also contends that structures of that height and above can be so located as to minimize the visual impact, and that retractable antennas could be used to address unusual aesthetic situations, such as in historic or scenic zones.[24] We do not believe that it would be prudent or that it is appropriate to set such a standard for amateur antennas and their supporting structures because of varying circumstances that may occur when a particular antenna configuration is under consideration, such as terrain or man-made obstructions. We believe that the policy enunciated in *PRB-1* is sound. *PRB-1* did not specify a particular height limitation below which a local government may not regulate.[25] The Commission did not want to mandate specific provisions that a local authority must include in a zoning ordinance.[26] We continue to believe that the standards the Commission set, that is, "reasonable accommodation" and "minimum practicable regulation", have worked relatively well. Therefore, we are not persuaded that changes to the Commission's policy of leaving the specifics of zoning regulations to the local authority, including provisions concerning the height of an amateur antenna, are necessary at this time.

9. Petitioner further requests that the Commission specifically preempt overly burdensome conditions and excessive costs levied by a local authority in connection with engineering certifications or issuance of antenna permits.[27] Specifically, Petitioner argues that assessment of unusual costs for processing an antenna permit application cannot be used by the local authority as a means of indirectly prohibiting the antenna.[28] Petitioner states that the same argument is true of conditional use permits that require an amateur antenna to be screened from view by the installation of mature vegetation.[29] According

---

[21] *MO&O* at 960, ¶ 25.

[22] Petition at 32 and 33.

[23] *Id.*

[24] *Id.* at 34.

[25] *MO&O* at 960, ¶ 25.

[26] *Id.*

[27] Petition at 34.

[28] *Id.* at 35.

[29] *Id.* at 36.

to the ARRL, if full vegetative screening cannot be accomplished in a cost-effective manner, a condition requiring such screening is a *de facto* prohibition.[30] Although Petitioner concedes that a municipality may require amateur operators to pay reasonable expenses to obtain amateur permits, the Petitioner objects to the imposition of unreasonable expenses because such expenses would discourage or prohibit the installation of amateur antennas.[31] Petitioner also requests that the Commission declare as invalid certain land use restrictions based on safety considerations, such as setbacks on the property where the antenna is to be erected, unless there are no other alternatives that would accomplish the same purpose.[32] Finally, Petitioner requests that the Commission specify that, if a local authority denies a conditional use permit or a special exception request, it still has the obligation to make a reasonable accommodation for amateur communications.[33] We return once again to the position that we have stated earlier in this *Order*, that is, that the standards of "reasonable accommodation" and "minimum practicable regulation" are sufficiently efficacious as guideposts for state, local and municipal authorities. We believe that the effectiveness of these guidelines or standards can be gauged by the fact that a local zoning authority would recognize at the outset, when crafting zoning regulations, the potential impact that high antenna towers in heavily-populated urban or suburban locales could have and, thus, would draft their regulations accordingly. In addition, we believe that *PRB-1's* guidelines brings to a local zoning board's awareness that the very least regulation necessary for the welfare of the community must be the aim of its regulations so that such regulations will not impinge on the needs of amateur operators to engage in amateur communications.

IV. Conclusion

10. In our view, Petitioner has not demonstrated that the clarifications requested are necessary. Accordingly, we conclude that the public interest would best be served by denying the ARRL request for modification and clarification of Commission policies and procedures concerning the limited preemption of state and local regulations that affect amateur service radio facilities.

V. Ordering Clause

11. Accordingly, IT IS ORDERED that, pursuant to Sections 4(i) and 303(r) of the Communications Act of 1934, as amended, 47 U.S.C. §§ 154(i) and 303(r), the petition for rule making, RM-8763, filed by The American Radio Relay League, Inc. on February 7, 1996, IS HEREBY DENIED. This action is taken under the delegated authority contained in Sections 0.131 and 0.331 of the Commission's Rules, 47 C.F.R. §§ 0.131 and 0.331.

FEDERAL COMMUNICATIONS COMMISSION

Kathleen O'Brien Ham
Deputy Chief, Wireless Telecommunications Bureau

---

[30] *Id.*

[31] *Id.* at 38.

[32] *Id.* at 44 and 45.

[33] *Id.* at 39.